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THE ABSORPTION OF LIGHT IN SPACE.

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It is the purpose of the present paper to call attention briefly to some of the evidence which has been presented by various investigators tending to show the existence of an appreciable absorption of light in passing thru interstellar space.

If it be granted that space is a perfect vacuum,—that is, containing only the ether,—then any diminution in the intensity of light passing thru it must be due to the ether itself. Now, it is assumed in the derivation of the equations of the electro-magnetic theory, that the ether is a perfect dielectric. The resulting expression for the velocity of propagation of an electro-magnetic disturbance appears, then, in a form which is independent of the frequency. This amounts to saying that light waves of all frequencies would travel with the same velocity in this medium, and there could be no dispersion or absorption of light in the ether. If we admit any conductivity of the ether, however small, the velocity at once becomes a function of the frequency, and we should have dispersion and absorption of light waves in this medium.

It is not possible, therefore, as some have apparently thought, to decide against the absorption of light by the ether on purely theoretical grounds, for we do not know that the ether is a perfect insulator.

On the other hand, there seems to be good reason for believing that space is not a vacuum, but that it contains an enormous mass of meteoric matter, and possibly gases which have escaped from stars. This matter would necessarily intercept some of the light of the stars, producing either a general absorption or a scattering of the light by small particles which would make its appearance as a selective absorption stronger for the blue than for the red rays.

At present we have no means of distinguishing as to which of these two media an absorption of light in space should be ascribed. It appears more probable, however, that it would be due to matter in some form in space rather than to the ether. In the present discussion we shall confine our attention to the question whether light suffers appreciable extinction in space apart from considerations of the medium by which it may be produced.

It is a well-known fact that a comparison of the number of stars of the successive orders of magnitude shows that the number corresponding to a given magnitude is approximately three times that belonging to the next brighter magnitude. Evidently this ratio of increase in number by magnitude cannot hold down to the very faint stars, for if it did, the sky would be a blaze of light. From a very careful enumeration of the number of stars by PICKERING[1] it is seen that this ratio decreases from 3.3 for the third to second-magnitude stars, to about 2.1 for that of thirteenth to twelfth magnitudes. That this decline in the rate of increase of the faint stars is due to the extinction of light of the fainter stars, which are on the average presumably the more distant, has been inferred by some.

A similar conclusion has been drawn by COMSTOCK[2] from his discussion of the mean parallax of stars of different magnitudes. On the hypothesis that the faint stars are of equal intrinsic brilliancy with the brighter ones, it follows from the known light ratio that a decrease of five magnitudes would correspond to a tenfold increase in distance. Taking the mean parallax of stars of magnitude 5.5, found by KAPTEYN, as $\pi = 0''.0158$, the mean parallax corresponding to magnitude 10.5, for example, should be $\pi = 0''.0016$. The value of the mean parallax for stars of magnitude 10.5 found by COMSTOCK is $\pi = 0''.0045$, almost three times that indicated by theory. He finds, however, that a good agreement between his determined mean parallaxes for different magnitudes and the computed values is given, when he introduces in his formula an absorption coefficient $a = 0.18$ magnitude. This coefficient of absorption a represents, in magnitude, the loss in brightness of a star when its light traverses the unit of distance of 32.6 light years, corresponding to a parallax $\pi = 0''.1$.

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[1] *H. C. O. Annals*, **48**, 149.

[2] *Astron. Jour.*, **24**, 43, 1904.

It must be remembered that the inferences of an extinction of light in space drawn above, from the number of stars of different magnitudes or from their mean parallax, are based implicitly upon either of two assumptions: (1) That all of the stars are equally bright, or (2) that they are equally distributed in space. The first of these is demonstrably false; the second is probably not true.

KAPTEYN[1] has derived the expression for the theoretical number of stars of a given magnitude and the value of their mean parallax, without introducing either of the above assumptions. From considerations of the proper motions of a large number of stars, together with other data, he has arrived at provisional values for the star density and magnitude curve on the tacit assumption that space is perfectly transparent. The number of stars of different magnitudes computed in this way is in good agreement with the number observed by PICKERING for each magnitude. Likewise, the mean parallaxes corresponding to different magnitudes deduced from his formula agree fully as well with the observed values as those computed by the formula of COMSTOCK on the assumption of an extinction of light in space. He does not conclude, however, that the above results show that there is no extinction of light. On the contrary he considers that they may be consistent with a small amount of absorption in space.

Upon what appears to be a reasonable hypothesis,—namely, that the intrinsically faint and bright stars are mixed in the same proportion at all distances from the Sun,—he computes the star density at different distances from us, which results from the assumption of different values of the coefficient of absorption a. For a value of $a = 0$ the star density decreases with increasing distance from the Sun, while for $a = 0.18$

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[1] *Astron. Jour.*, **24**, 115, 1904.

(COMSTOCK's value) it increases rapidly as we proceed outward from the Sun. Either value of a assigns to the Sun a unique position in space, that of maximum or minimum star density. A value of $a = 0.016$ leads to practically a uniform distribution of the stars at different distances. KAPTEYN recognizes the provisional nature of the data from which this value of the coefficient of absorption is deduced and does not propose it for acceptance. He merely considers that there is some reason to believe that the average absorption must be of this order of magnitude.

If it can be shown that light waves of different frequencies travel with different velocities in interstellar space, we may at once infer that the medium in which this dispersion takes place will also produce absorption of the energy of these waves.

An attempt to detect the existence of dispersion of light in space has been made by two observers, NORDMANN[1] and TIKHOFF,[2] from observations of eclipsing variables. If the blue rays travel with a smaller velocity than the red ones, the time of minimum of an Algol variable determined from photometric observations in its blue light, should occur later than the minimum determined from like observations in its red light. It is evident that the determination of this time interval for an eclipsing variable whose distance from us is known would afford a method of determining the distances of other variable stars of this class, from observations of their time intervals between red and blue minima. NORDMANN's method consisted in photometric observations of the variable made visually in succession thru three colored screens, each transmitting only one third of the visible spectrum—red, green and blue. For *Algol* he finds that the minimum when observed in blue light of wave-length 4300 A occurs about sixteen minutes later than when it is observed in red light of wave-length 6800 A. The time interval between the blue and red minimum for λ *Tauri* is about three times as great as that for *Algol*.

TIKOFF's observations were made photographically, using colored gelatine filters for isolating the different regions of the spectrum. He found for RT *Persei* that the minimum observed in light of wave-length 4300 A occurred four minutes later than that observed in light of wave-length 5600 A. The retardation of the minimum for rays 3800 A with respect to that for orange light 6250 A was found to be about ten minutes for W *Ursæ Majoris,* a star showing continuous variation in light.

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[1] *C. R.*, **146**, 266 and 383, 1908.

[2] *C. R.*, **146**, 570, 1908; *ibid*, **148**, 266, 1909.

In the methods of NORDMANN and TIKOFF it is a question of observing the velocities of groups of waves and not those of individual waves. If the observed retardation of the blue with respect to the red rays be assumed to be due to dispersion of light in space, the observed retardation of the groups of waves must be divided by three in order to obtain the dispersion of this medium in the ordinary sense—that is, the dispersion of individual waves. In order to arrive at an idea of the amount of dispersion in space NORDMANN accepts a value of the parallax of *Algol* corresponding to a distance of sixty light years, while TIKOFF assumes that the distance of RT *Persei* is 740 light years.

LEBEDEW[1] calls attention to the fact that the results for space dispersion obtained by these two observers differ more than 30 to 1 and concludes "that a method which yields such widely different results for the same constant cannot be anything else than incorrect and therefore wholly inapplicable." He further points out that thru a medium producing an amount of dispersion found by NORDMANN and TIKOFF, no appreciable part of the light of the stars or even of the Sun, could reach the Earth. His objections to ether dispersion on the ground of the electro-magnetic theory are not well taken, for reasons stated earlier in this paper. It would appear that the discrepancy between the results obtained for space dispersion may, at least in part, be due to the very doubtful values of the parallaxes assumed for *Algol* and RT *Persei.* The method of monochromatic photometry, especially that used by NORDMANN, would seem to be adequate for detecting a time lag in the minima of *Algol* variables of the order found by these observers. It appears probable that the above results obtained for eclipsing variables are not to be explained by a dispersion of light in space, but are to be attributed rather to the peculiar physical properties of these stars.

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[1] *Aph. Jour.*, **29**, 101, 1909.

TIKOFF has brought forward another result as evidence of space dispersion, which is based upon data obtained by BELOPOLSKY and himself for the spectroscopic binary *β Aurigæ*. The spectra of both components are visible upon spectrograms of this star. From measures of plates secured in two regions of the spectrum—the blue (4420 to 4620 A) and the violet (3930 to 4100 A)—the epochs of coincidence of the lines of the two spectra were computed. He found that this epoch deduced from the spectrograms taken in the violet is delayed 0.015 days with reference to that obtained from the spectrograms secured in the blue region. An inspection of the data upon which this result is based shows, however, that little or no weight is to be attached to this observation.

From our knowledge of the phenomena of light in media with which we are familiar we should be led to infer that an absorption of light by a medium in interstellar space would be selective in that the blue rays would be affected more strongly than the red ones. As a result of space absorption of this nature it would follow that the more distant stars should appear redder than those nearer to us. Several methods of attacking this problem have been proposed, and it would appear that in some of these we have promise of finally obtaining an answer to the very difficult question whether light suffers absorption in space.

Now it is well known that the degree of redness of stars depends upon their type of spectrum; that is, upon the physical constitution of the atmosphere of these stars. In comparing the redness of stars at different distances it is essential, then, that the stars observed be of exactly the same spectral type.

KAPTEYN[1] has called attention to the fact that in the classification of stellar spectra Miss MAURY has divided those of Class XVa into two groups, of which the spectrum of *α Bootis* is characteristic of one division and that of *α Cassiopeiæ* of the other. The spectra of stars of the *α Bootis* division show slight general absorption in the violet, while for those of the *α Cassiopeiæ* group the absorption in the violet is more conspicuous and to the violet of 3889 A their spectra are suddenly cut off. We appear to have here stars of the same spectral type which differ only in the amount of the absorption of their violet rays. If this difference be due to selective space absorption, we should expect to find the stars of the *α Cassiopeiæ* group to be the more distant.

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[1] *Aph. Jour.*, **29**, 46, 1909.

From a discussion of the available proper motions of the twenty-five stars of the *α Boötis* division and of the forty-five of the *α Cassiopeiæ* group, KAPTEYN finds:—

	α Cassiopeiæ division.	*α Bootis* division.
Number of stars of centennial proper motion < 10″	58%	20%
Number of stars of centennial proper motion > 30″	0%	48%

On the assumption that the stars having small proper-motions are on the average more distant than those with large proper-motions, the above evidence would point to the conclusion that the stars of the *α Cassiopciæ* group are in general more distant than those of the *α Bootis* division. Evidence is thus afforded by the stars in question that the violet portion of their spectrum is relatively fainter for those stars which are the more distant. Inasmuch as the average apparent magnitude of the stars of the two groups is about the same, the luminosity of the stars of the more distant *α Cassiopeiæ* group must be greater than that of the *α Bootis* division. KAPTEYN points out that the above result does not necessarily indicate a selective absorption of the violet light in space, but may mean that for stars of the same spectral type the light of the more luminous objects is relatively weaker in the violet part of the spectrum.

An investigation which is in principle the same as the one just cited is being conducted by Mr. ADAMS[1] with a one-prism spectrograph attached to the 60-inch reflector at Mount Wilson. His method consists in photographing upon the same plate the spectra of two stars which are of exactly the same spectral type, one of which is known to be near to us and the other, from its small proper-motion, presumed to be distant. A com parison of the relative intensities of the two spectra at 5000 A and 4200 A for a few pairs of stars showed that on most of the plates the spectrum of the star presumed to be the more distant was relatively weaker in the violet than that of the star of large proper-motion. Some pairs showed little or no difference, but in no case was the spectrum of the star of small proper-motion stronger in the violet. More recently[1] he has attempted to utilize the large number of radial-velocity spectrograms secured at Mount Wilson for the same purpose. These were compared with a standard plate of *α Tauri* on the spectrocomparator and estimates of their relative intensity at 4549 A and 4220 A were made. As a result of this discussion he finds that: (1) The violet end of the spectrum of stars of small proper-motions is decidedly weaker than for those of large proper motions; (2) this difference is less for Class F stars and increases with the spectral type at least as far as Class K stars. As the average proper-motions of the different groups of stars of Classes F to K used in the discussion are so nearly the same, it seems probable that at least part of the observed difference in the absorption of the violet rays is due to physical differences in the stellar atmospheres.

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[1] *Aph. Jour.*, **39**, 89, 1914.

As mentioned above, the stars assumed to be more distant in making these comparisons must in general be the more luminous, and presumably larger than those considered to be near us. That the atmosphere of a large massive star would show greater selective absorption for violet light than that of a small and less massive one seems reasonable from physical considerations. In order to ascribe the observed difference in the absorption of the violet rays to a selective absorption in space it will be necessary to show that it is not due to the cause just cited—that is, to what KAPTEYN calls the effect of absolute magnitude. A comparison of the relative intensities of stars of the same spectral type which are known to be at about the same distance from us, but which differ greatly in absolute magnitude, would undoubtedly throw some light upon this question. The components of some visual binaries should satisfy these conditions.

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[1] *Publ A. S. P.*, **26**, 90, 1914.

An effort has been made by KAPTEYN[1] to obtain some quantitative determination of the space absorption by taking, as a measure of the degree of redness of the stars, the difference between the photographic and visual magnitudes, and as a measure of average distance the apparent magnitudes and proper motions of these stars. The discussion is based upon 1,433 stars whose photographic magnitudes are taken from the Draper Catalog and the visual magnitudes from the Harvard Revision. He puts,—

$$\text{Photo. Mag.} - \text{Vis. Mag.} = a + b\,m + c\,M + d\,\Delta,$$

where Δ is equal to unit distance of 32.6 light years, and m and M are the apparent and absolute magnitudes, respectively. The constant a is dependent upon the class of spectrum, b is the change of redness per unit of apparent magnitude, c the change of redness per unit of absolute magnitude, and d the increase of redness per unit of distance. He proceeds then to determine the values of these constants from all the available data.

Some difficulty is experienced in the derivation of c as the data are sufficient to give only a good determination of $d - 0.25\,c$. From the value of c, which he finally derives on certain assumptions, he finds that $d = 0.0031 \pm 0.0006$ mag. This value of d would correspond to a loss of light for a distance of 32.6 light years, for the visual rays of 0.0028 magnitude and for the blue rays of 0.0057 magnitude. He finds, moreover, that there is no evidence of a difference of absorption in different directions in space.

Mr. KING[2] has applied the same method to a discussion of his photometric observations for twenty-six stars. The constant a was eliminated by using the deviations of the difference photo.mag — visual mag. for each star from the mean of its class of spectrum. To eliminate b a grouping of the deviations for 150 stars was made with respect to the magnitude, and the small corrections thus obtained were applied to the deviations of the twenty-six stars. He finds $d = 0.019 \pm 0.010$ magnitude, indicating a loss of 0.0377 magnitude for the photographic rays, and 0.0184 magnitude for the visual rays, while traversing the distance of 32.6 light years. More recently[1] he has combined the results for the above twenty-six stars and those for twenty-two additional ones. By selecting from these the twenty-five stars whose parallaxes are based upon the work of two observers, he obtains $d = 0.0189 \pm 0.0065$ magnitude, a value which is practically identical with that previously found. The value of the loss of light per unit distance found by him is more than six times that derived by KAPTEYN from his similar discussion. It is of interest to note that his value for the loss in the visual rays, of 0.018 magnitude, is in good agreement with that which KAPTEYN regards as a probable value from his discussion of the distribution of the stars referred to above—namely, 0.016 magnitude.

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[1] *Aph. Jour.*, **30**, 284, 1909.

[2] *H. C. O. Annals*, **59**, 179, 1912.

The evidence that the faint stars are appreciably redder than the bright ones is accumulating from photometric and spectroscopic observations. One of the most recent contributions is that of HERTZSPRUNG.[2] He has photographed numerous regions with a large grating attached to the tube of the 60-inch reflector at Mount Wilson for the purpose of determining the effective wave-lengths of the light of the faint stars. On his plates of the field containing the cluster N. G. C. 1647 he finds that from the ninth magnitude on there is a gradual increase in the effective wave-length, indicating that the fainter stars are redder than the brighter ones.

To sum up the results to which we have referred concerning the degree of redness of the stars, existing evidence strongly indicates the reality of the two following phenomena:—

(1) Apparent magnitudes and spectral lines being the same, the stars are redder the more distant they are from us.

(2) On the average, the fainter stars are redder than the brighter ones.

Whether or not the explanation of these phenomena be selective absorption of the violet rays, it is impossible to say from our present knowledge, altho it seems probable that absorption of light in space may play at least some part in their production. Whatever their explanation, these two phenomena are of the greatest importance.

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[1] *H. C. O. Annals*, **76**, 1.

[2] Annual Report of the Director of the Mount Wilson Solar Observatory, Year Book of the Carnegie Institution, No. 12.

An attempt has been made to throw some light upon the question of the existence of space absorption from still another point of attack by Mr. F. G. BROWN.[1] His method consists in comparing the average brightness of the nebulæ of different diameters, on the assumption that on the average the objects with a small apparent diameter must be more distant than the larger objects. If there were no absorption of light in space the intrinsic brightness of a nebula would be the same whatever is its distance from us. If the light is partly absorbed, the average brightness of the smaller objects would be less than that of the larger ones. The data upon which he bases his discussion is derived from the descriptions contained in the *New General Catalogue*. It must be said that even with the very unreliable data which he had at hand, the results show a marked decrease in average brightness of the nebulæ with decreasing diameter. It would seem that the method would be capable of yielding results of importance if reliable photometric and micrometric measures of a large number of nebulæ were available.

In reviewing the evidence which has been deduced in favor of an absorption of light in interstellar space, it appears that the individual results obtained by any one of the above methods, while they may be explained on the assumption of a small amount of space absorption, do not point conclusively to this as the true explanation. However, the fact that we have been led to the same indication of an absorption of light in space by several different methods based on different assumptions lends some probability to its existence.

May, 1914.

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[1] *Monthly Notices R. A. S.*, **72**, 195 and 718.